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# Modeling Post-fire Successional Trajectories under Climate Change in Interior Alaska using Landis II

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# Modeling post-fire successional trajectories under climate change in Interior Alaska using LANDIS-II

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Systems Science Seminar. February 14, 2020

# How did I find modeling?

**B.S. at Colorado State**

- -Wildlife Biology
- -Statistics (minor)

**Seney National Wildlife Refuge, MI**

- -Big landscape
- -Management
- -Field surveys and experiments

**M.S. at Ohio State University**

- -Forest/wildlife management
- -Fire as an ecological restoration tool

**Earth, Environment & Society Doctoral Program, PSU**

- -Boreal forests in Alaska
- -Big landscape
- -Climate change & wildfire
- -Modeling

**Missouri Botanical Garden**

- -Databases
- -Ex-situ species conservation

# Outline of Today's Seminar

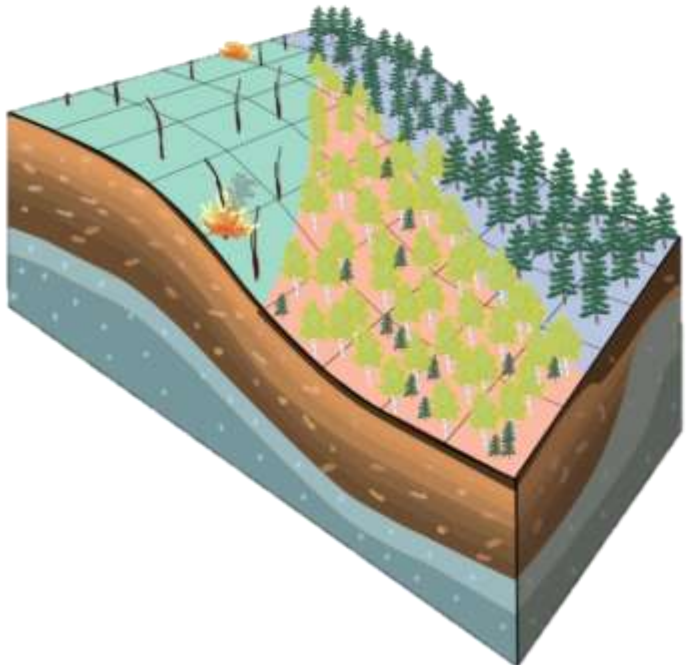
- Modeling
- LANDIS-II

- Alaska example

# Purpose of Models

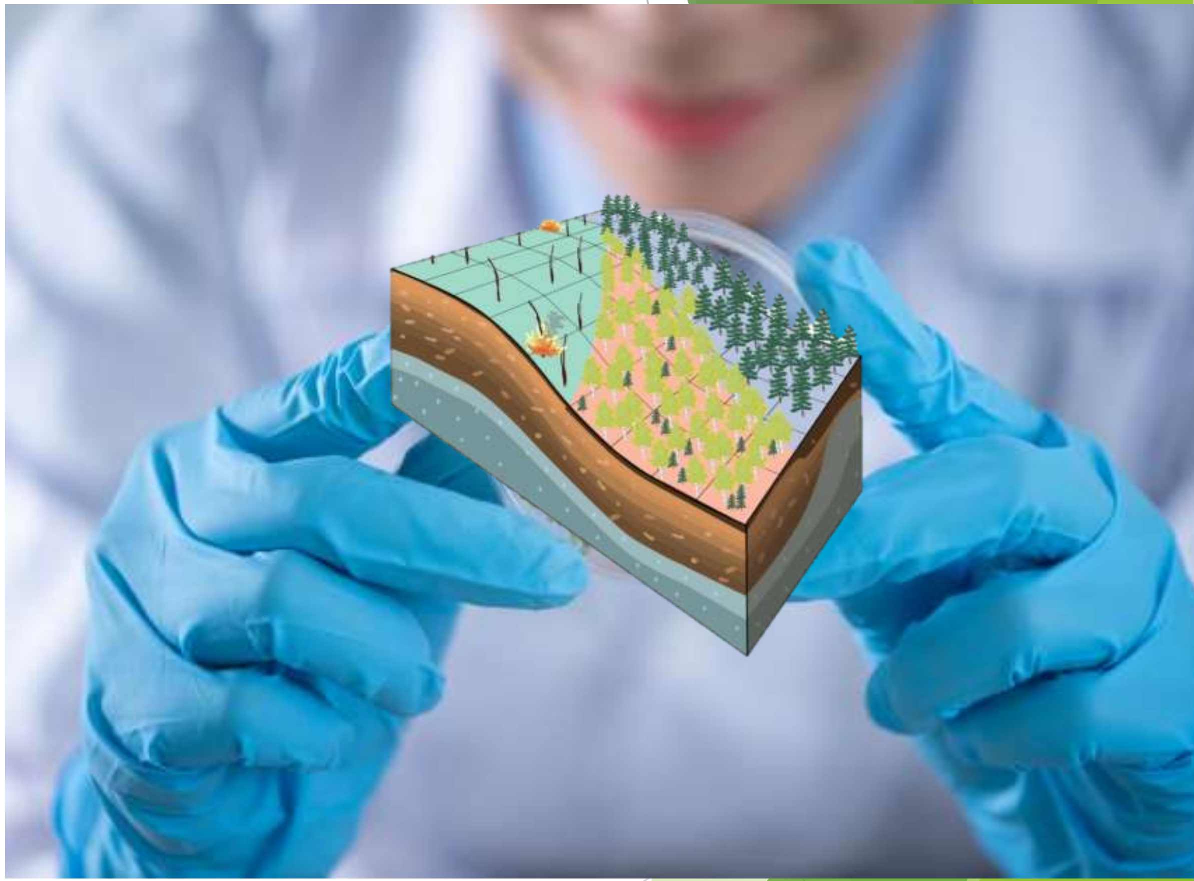
*A model is a representation of a system or process*

- To provide a framework for data and organizing ideas
- To explore real or hypothetical scenarios
- To make predictions; extrapolate across scales or time



# What can we do with models?

- We can answer big questions!
  - Processes
  - Potential futures
    - We could have a “no analog” future
  - Management
  - Scenario Planning



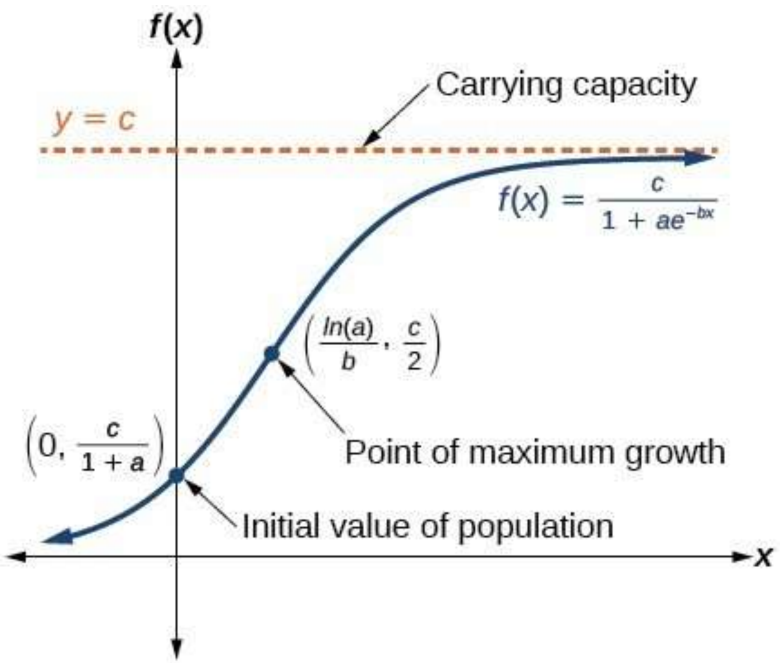
- We can conduct experiments (with replicates!) at large scales that we wouldn’t be able to otherwise

- We can compare across many conditions, and manipulation of these conditions

# Types of models

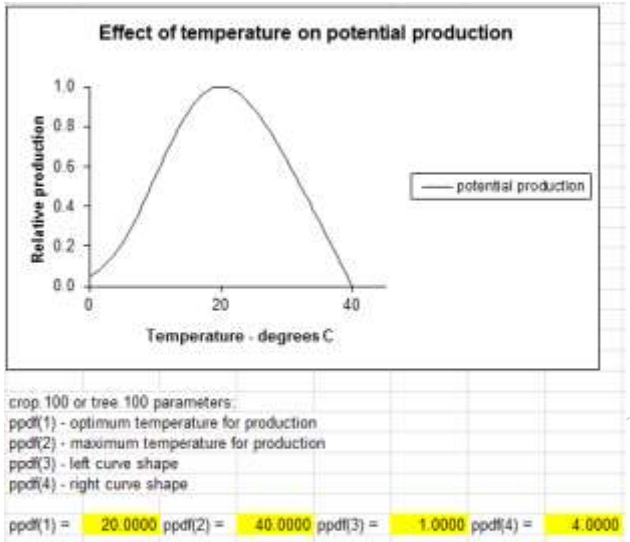
## Analytical models

- Have a closed-form mathematical solutions
- Changes in a system can be expressed as a mathematical function




## Simulation models

- Use mathematical and logical operations to represent the structure and behavior or a system
- Lack a closed-form solution
- Often complex
- Dynamic- the system or phenomenon may change through time.




# Common types of vegetation simulation models

- Dynamic Global Vegetation Model (DGVM)
- State-and-Transition Model
- Landscape Model

# Dynamic Global Vegetation Models

- Used to simulate effects of climate change on vegetation, carbon and water cycles
- Large scales
- Captures feedbacks from vegetation change/disturbance to the atmosphere
- Questions can include:
  - Response of veg to CC
  - Estimate changes in carbon pools/fluxes

Global Change Biology (2015) 21, 4548–4560, doi: 10.1111/gcb.13048

## Projected carbon stocks in the conterminous USA with land use and variable fire regimes

DOMINIQUE BACHELET[1], KEN FERSCHWEILER[1], TIMOTHY J. SHEEHAN[1], BENJAMIN M. SLEETER[2] and ZHILIANG ZHU[3]
[1]Conservation Biology Institute, Western Geographic Science Center, Menlo Park, CA, USA, [2]U.S. Geological Survey, Western Geographic Science Center, Menlo Park, CA, USA, [3]U.S. Geological Survey National Center, Reston, VA, USA

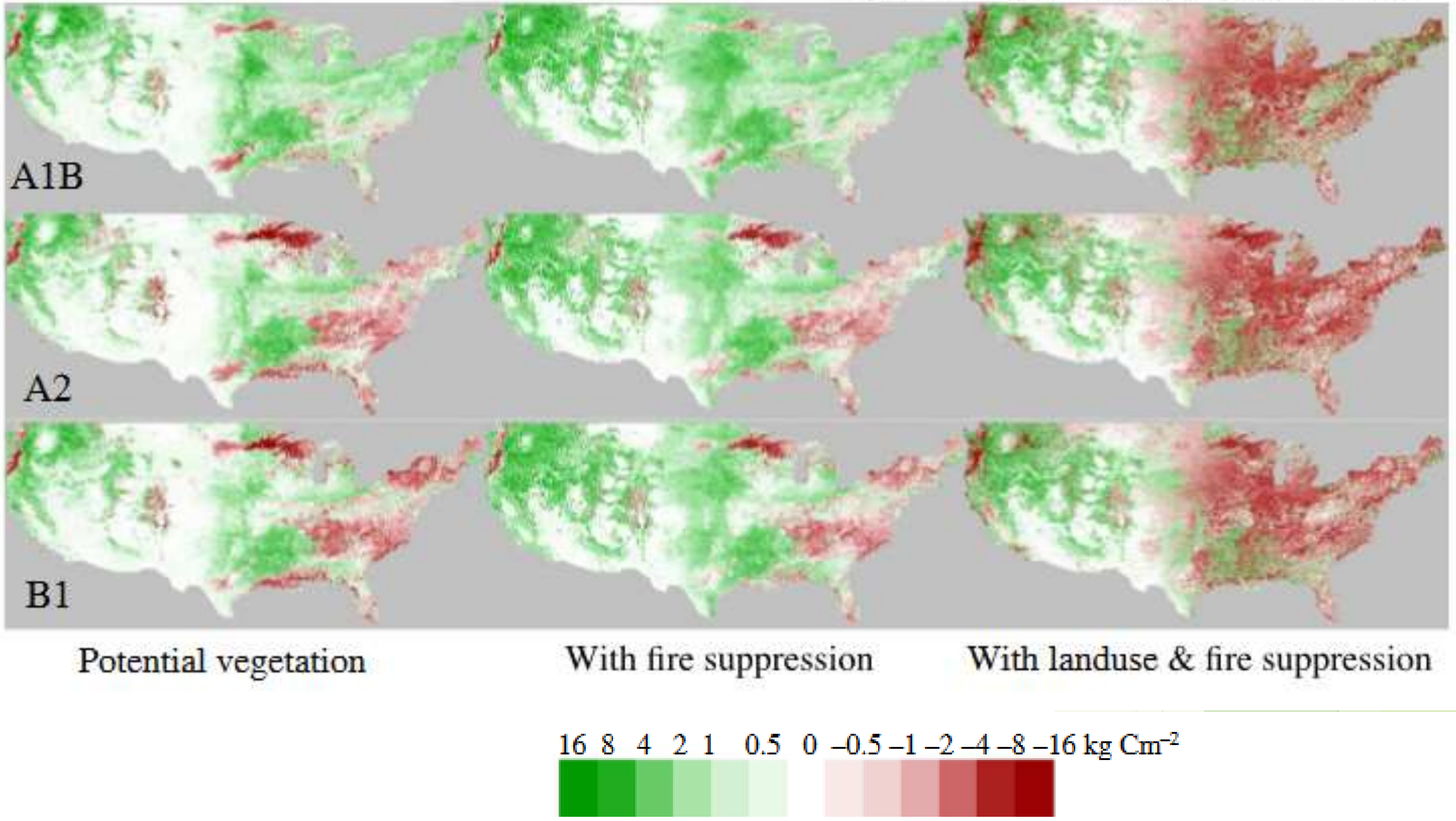
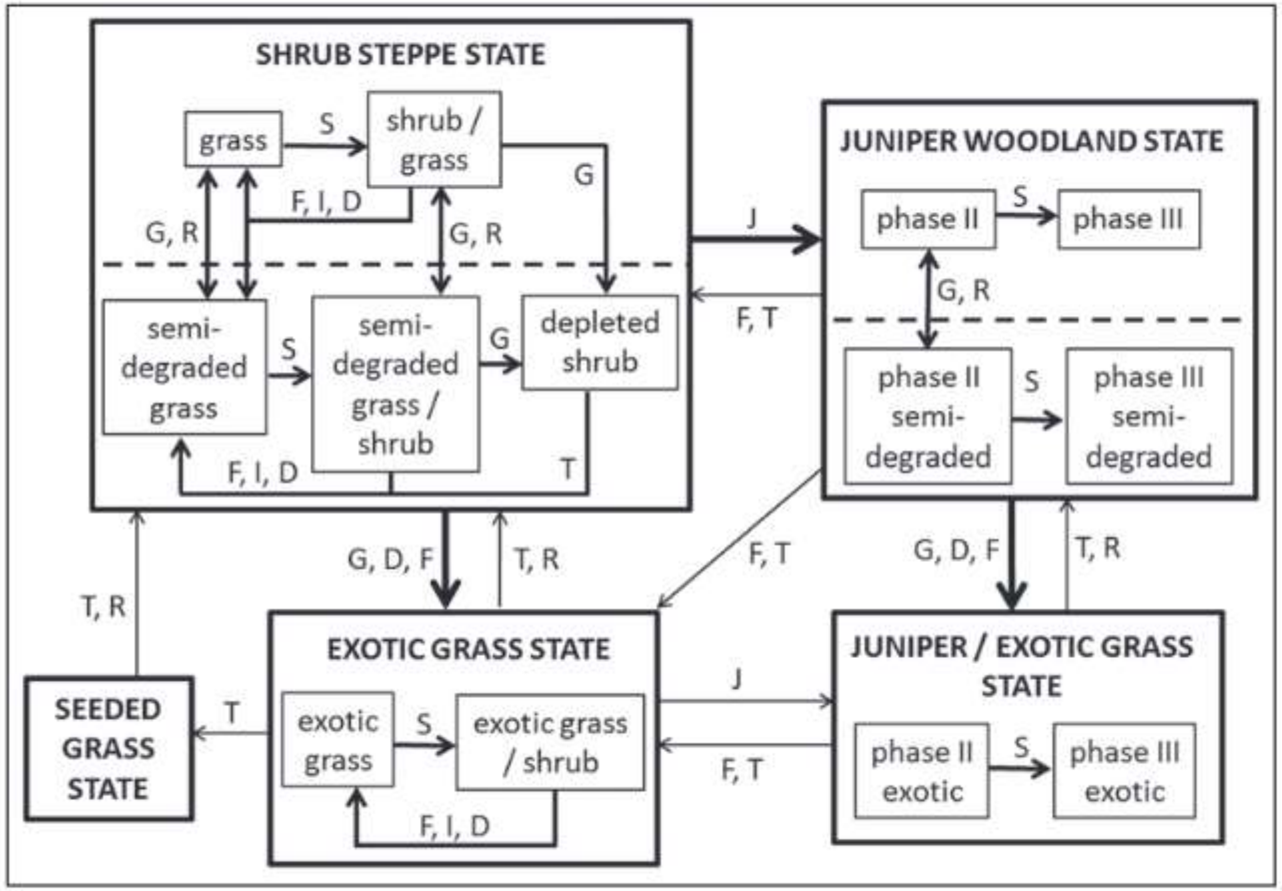



**Fig. 4** Simulated change in ecosystem carbon density (kg C m$^{-2}$) from historical conditions (2001–2005 average) to mid-century (2041–2060 average) under 3 emission scenarios (A1B, A2 and B1) averaged across three GCMs (MIROC, CSIRO and CGCM3).

http://onlinelibrary.wiley.com/doi/10.1111/gcb.13048/epdf

# State-and-Transition Models

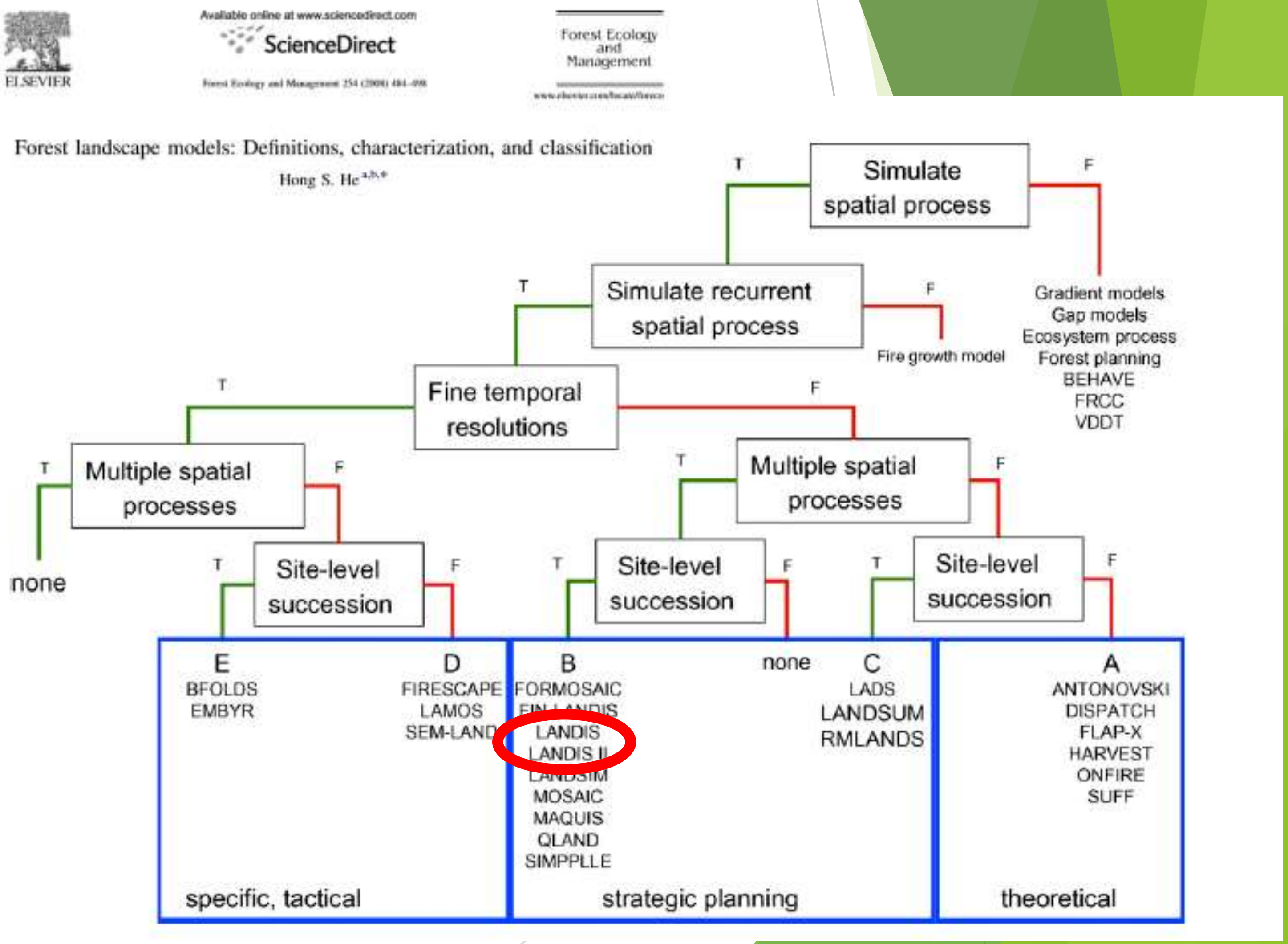
- User defines the developmental states (boxes) and pathways (arrows) between them
  - growth, disturbance, management, etc
- The states and pathways are predetermined before running the model
- Not species-level
- Can model shifts to a wide range of vegetation types
- Can easily test alternative hypotheses about veg dynamics or management strategies




https://www.fs.fed.us/pnw/pubs/pnw_gtr869/pnw_gtr869_006.pdf

# (Forest) Landscape Models

- Large spatial and temporal scales
- Differ from one another the ecological processes and level of detail they simulate
- Can be species (or even individual)– level
- Can ask questions about the outcomes of repeated, stochastic spatial processes
  - seed dispersal, fire, wind, insects, diseases, harvests, and fuel treatments
  - **Allows for no-analog futures!**



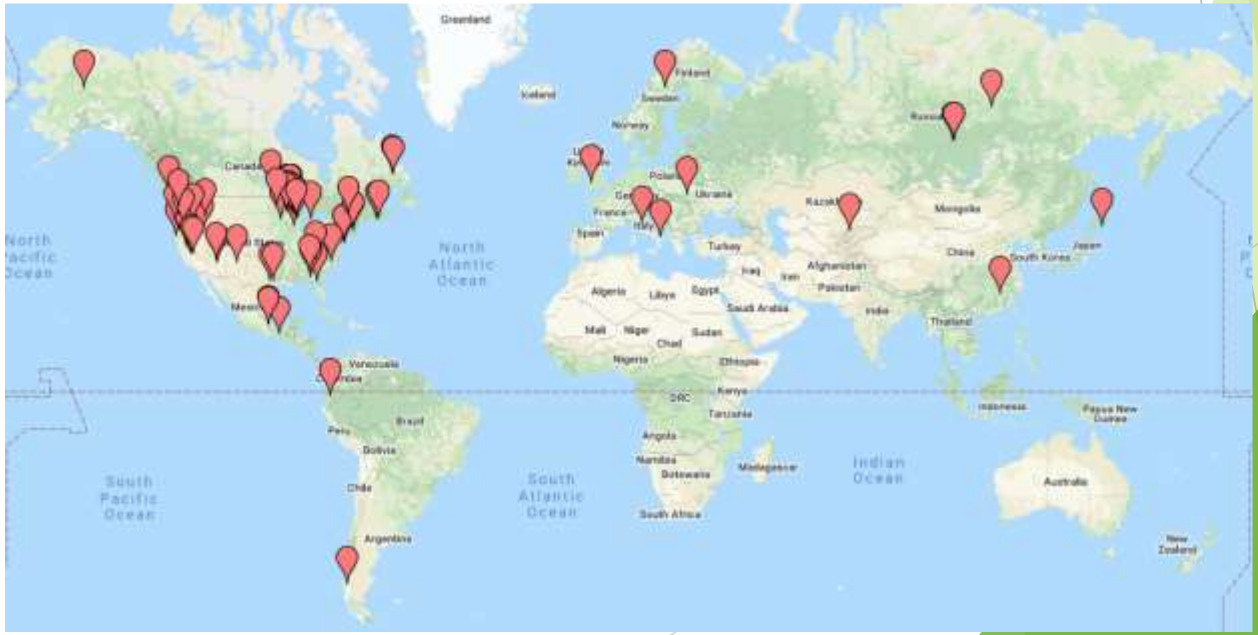
# LANDIS-II

LANDscape DISturbance and Succession

The LANDIS family of forest landscape models have been around for > 30 years.

LANDIS-II is > 20 years old.

Open source!




www.landis-ii.org

# LANDIS-II Simulates Succession

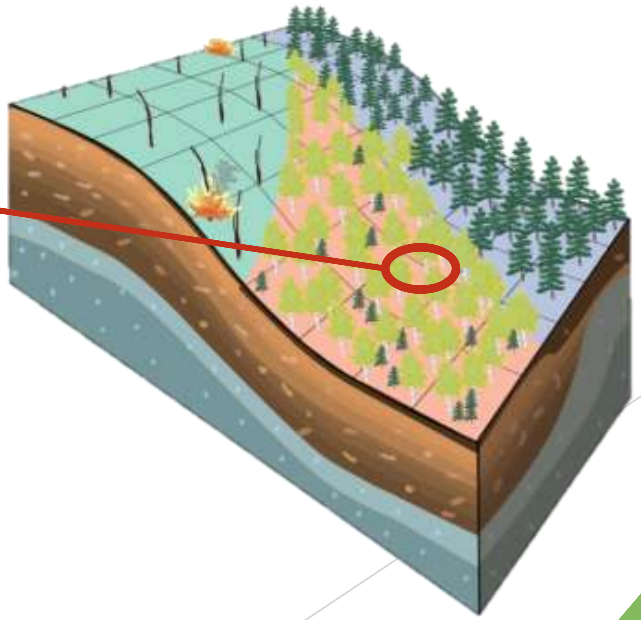
- An emergent property of species life-history attributes, disturbance, and dispersal
- No single pathway
- Responds **dynamically** to climate change, introduced species, novel disturbance regimes, etc.

Example cohort

Paper Birch White Spruce

21-30 years old

5 Mg $ha^{-1}$



# Life History Attributes

- Life history attributes can include chemical and physiological properties.

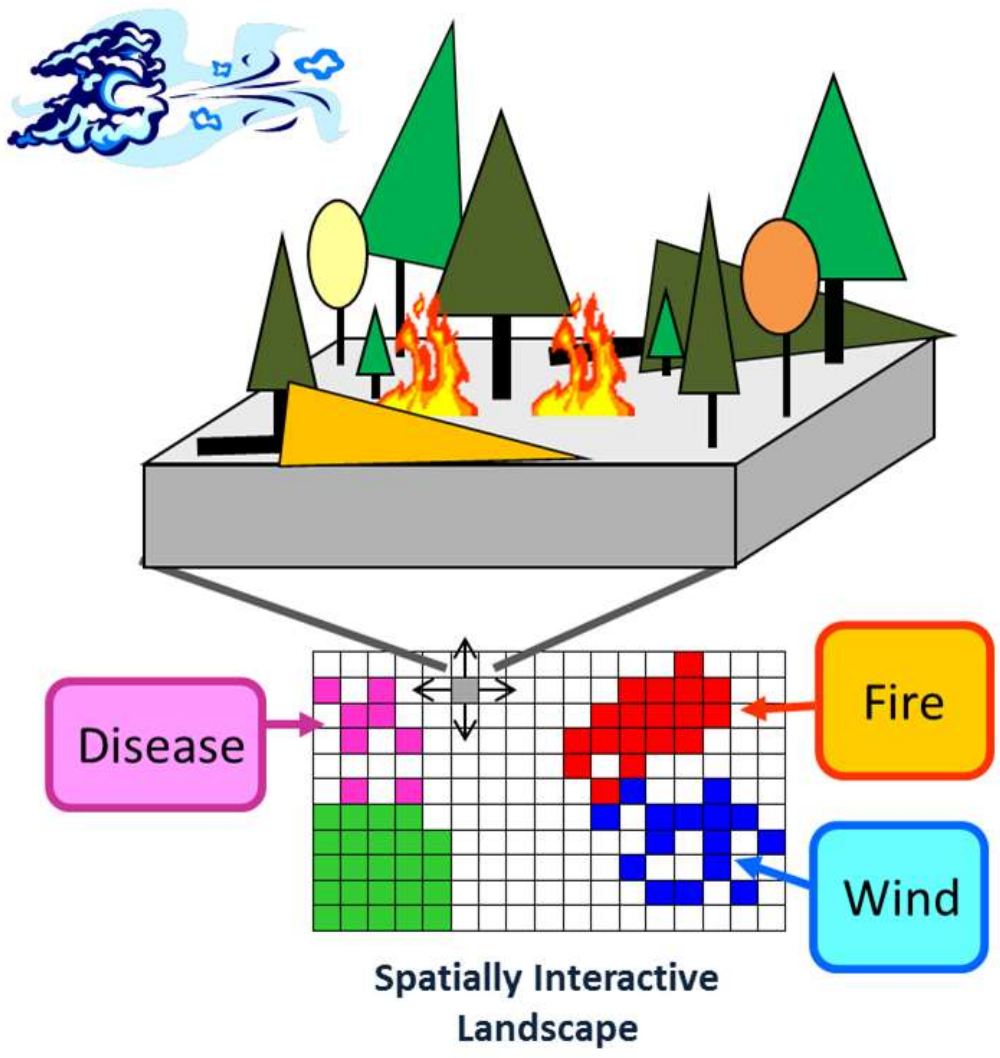
LandisData      Species

| >> | Name | Long | Sexual Maturit | Shade Tol. | Fire Tol. | Seed Disp Dist Effecti | Seed Disp Dist Maximum | Veg Rep P | Sprout Min | Age Max | Post-Fire Regen |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BlackSpruce | 200 | 30 | 4 | 1 | 20 | 60 | 0 | 0 | 0 | serotiny |
| | WhiteSpruce | 250 | 30 | 3 | 2 | 60 | 400 | 0 | 0 | 0 | none |
| | PaperBirch | 200 | 15 | 2 | 1 | 60 | 200 | 0.6 | 1 | 75 | resprout |
| | QuakingAspen | 200 | 10 | 1 | 1 | 500 | 5000 | 0.9 | 1 | 200 | resprout |
| | Tamarack | 180 | 15 | 1 | 1 | 63 | 200 | 0 | 0 | 0 | none |
| | Willow | 70 | 2 | 2 | 2 | 50 | 5000 | 0.9 | 1 | 70 | resprout |
| | Alder | 70 | 4 | 3 | 2 | 50 | 100 | 0.6 | 1 | 70 | resprout |
| | BalsamPoplar | 200 | 8 | 1 | 3 | 200 | 3000 | 0.8 | 1 | 200 | resprout |

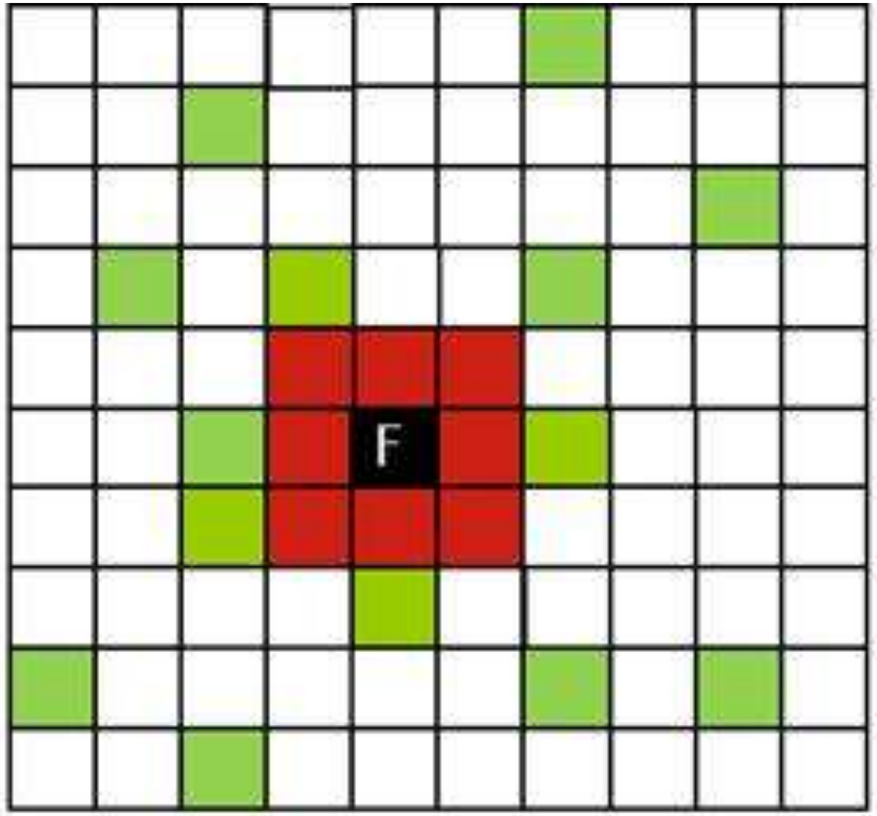


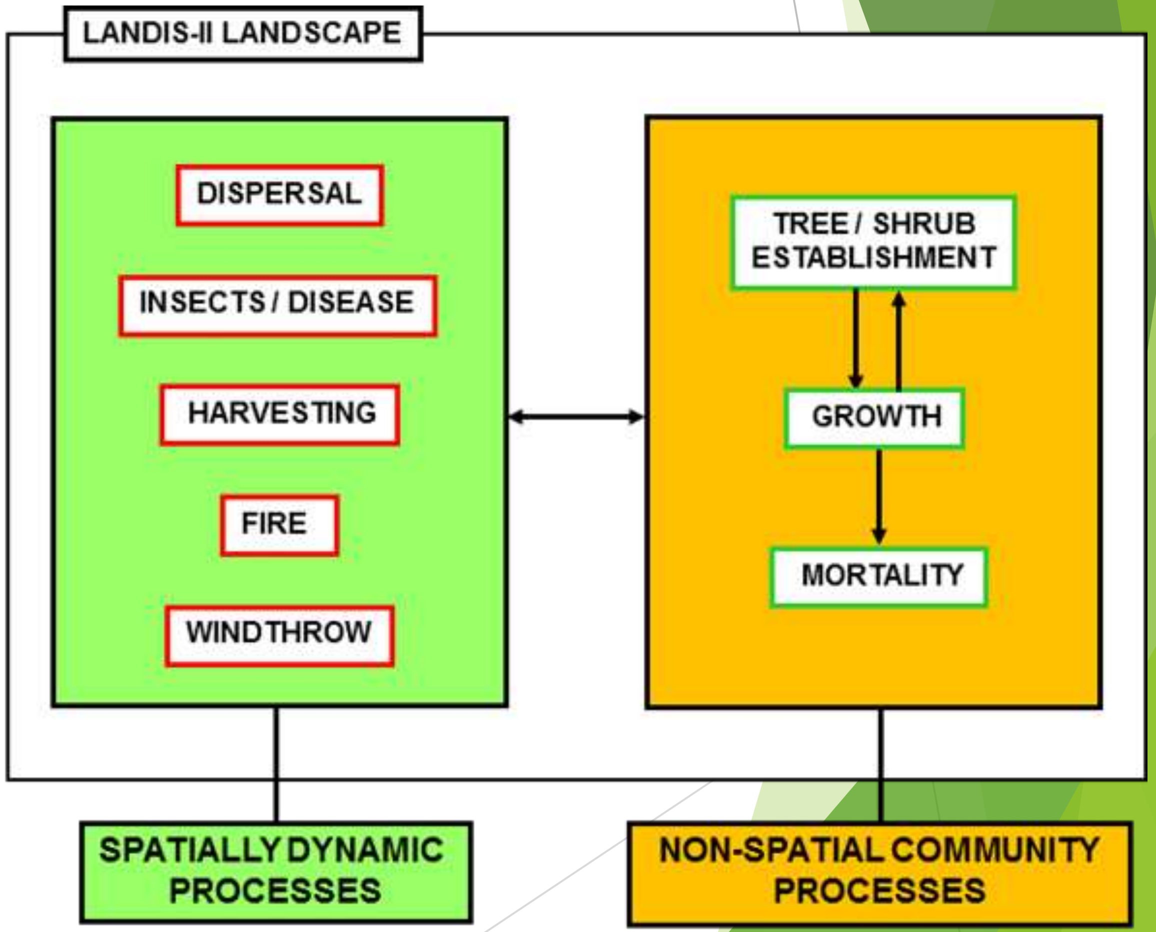

# LANDIS-II Simulates Disturbance

- Fire, wind, harvesting, insects, fuels management, drought…
- Disturbance events are stochastic and dependent upon probabilities
- Disturbances overlap in space and time



# Spatially Explicit and Spatially Dynamic (…though not always)

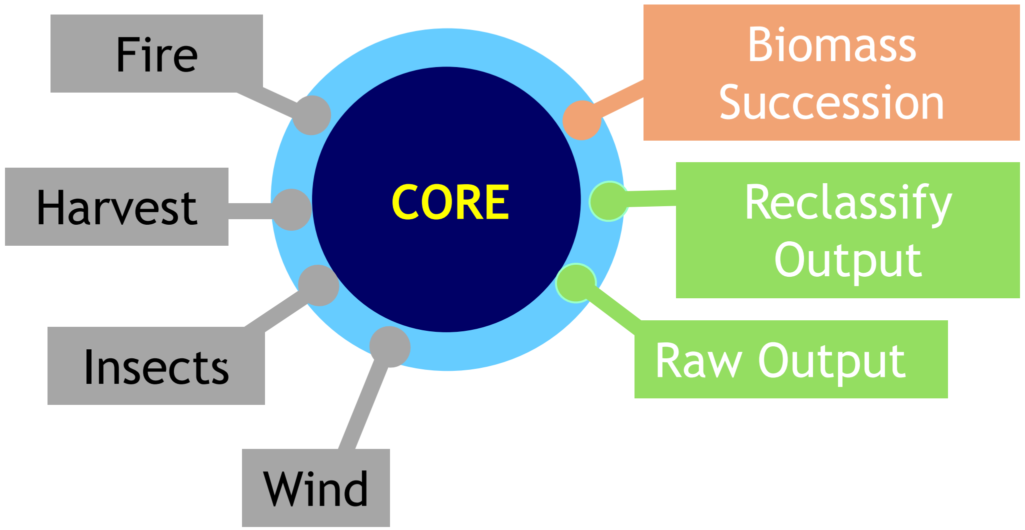


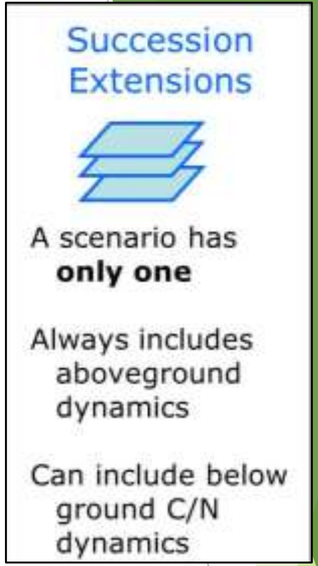



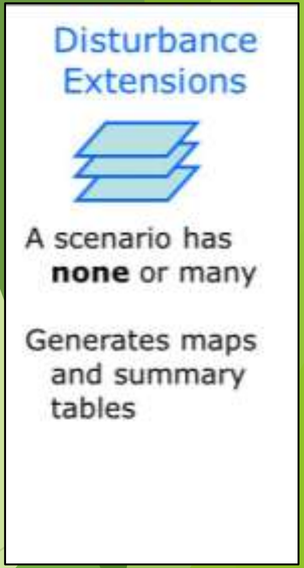
# User Determined Complexity

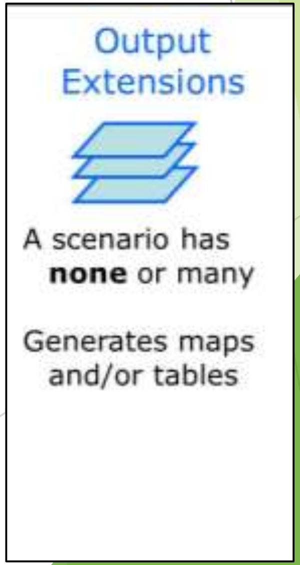
LANDIS-II has a Core and many extensions.

There can be many different extensions for each process: *different questions = different extensions*.  Extensions have varying degrees of complexity.



# Fast Model Evolution

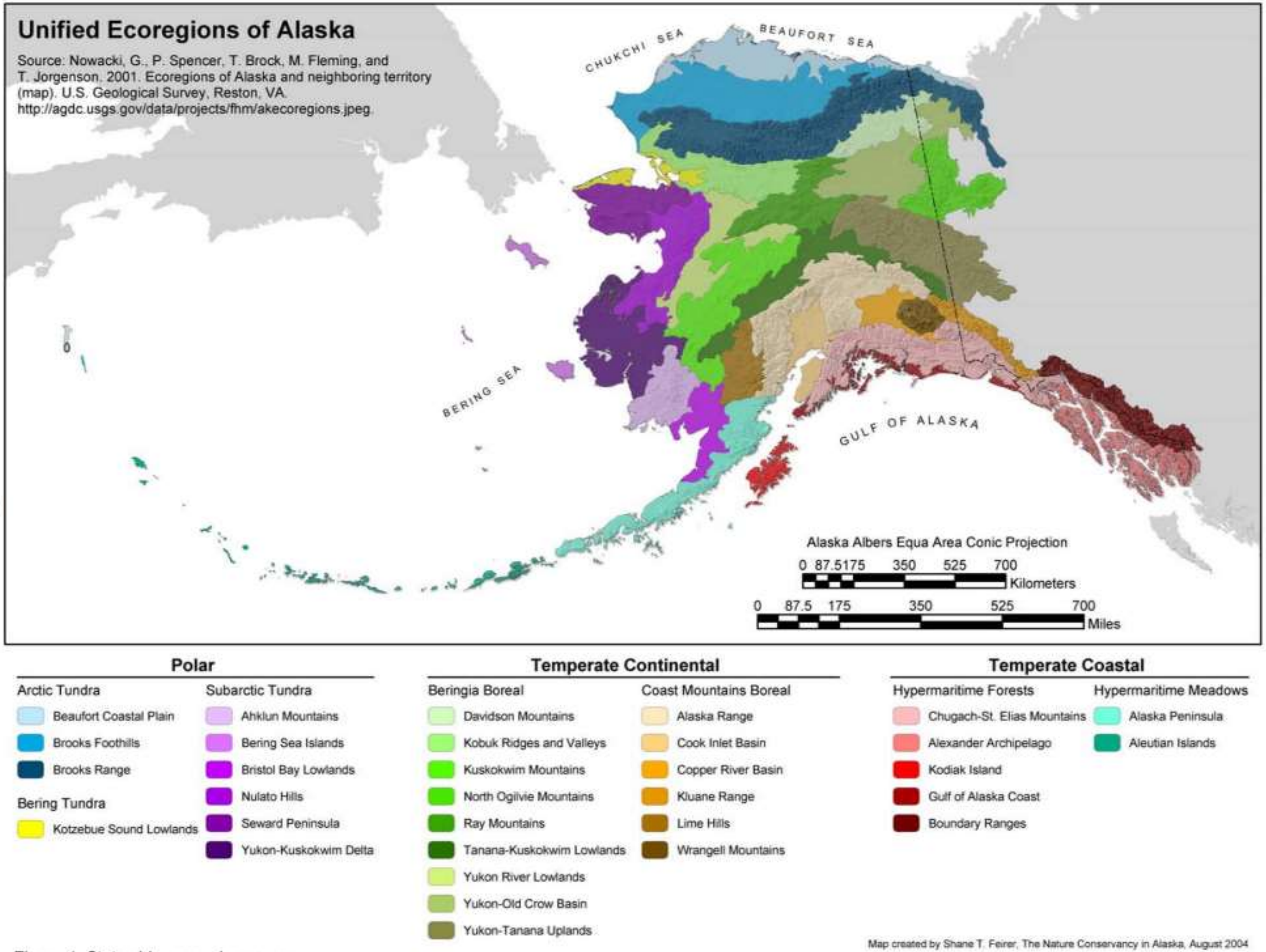
Extensions are **open source** and easily modified.

extensive documentation at multiple levels

Scientists can download extension code and tweak or rewrite as necessary

# Characterizing shifts in species composition and C source/sink status due to fire and climate change

*Lucash, Buma, Link, Romanovsky, Vogel, Nicolsky, Scheller*




**The boreal forest is the world’s largest terrestrial biome and holds an estimated 30-50% of the global stocks of forest carbon**

**(…and we are probably underestimating this)**

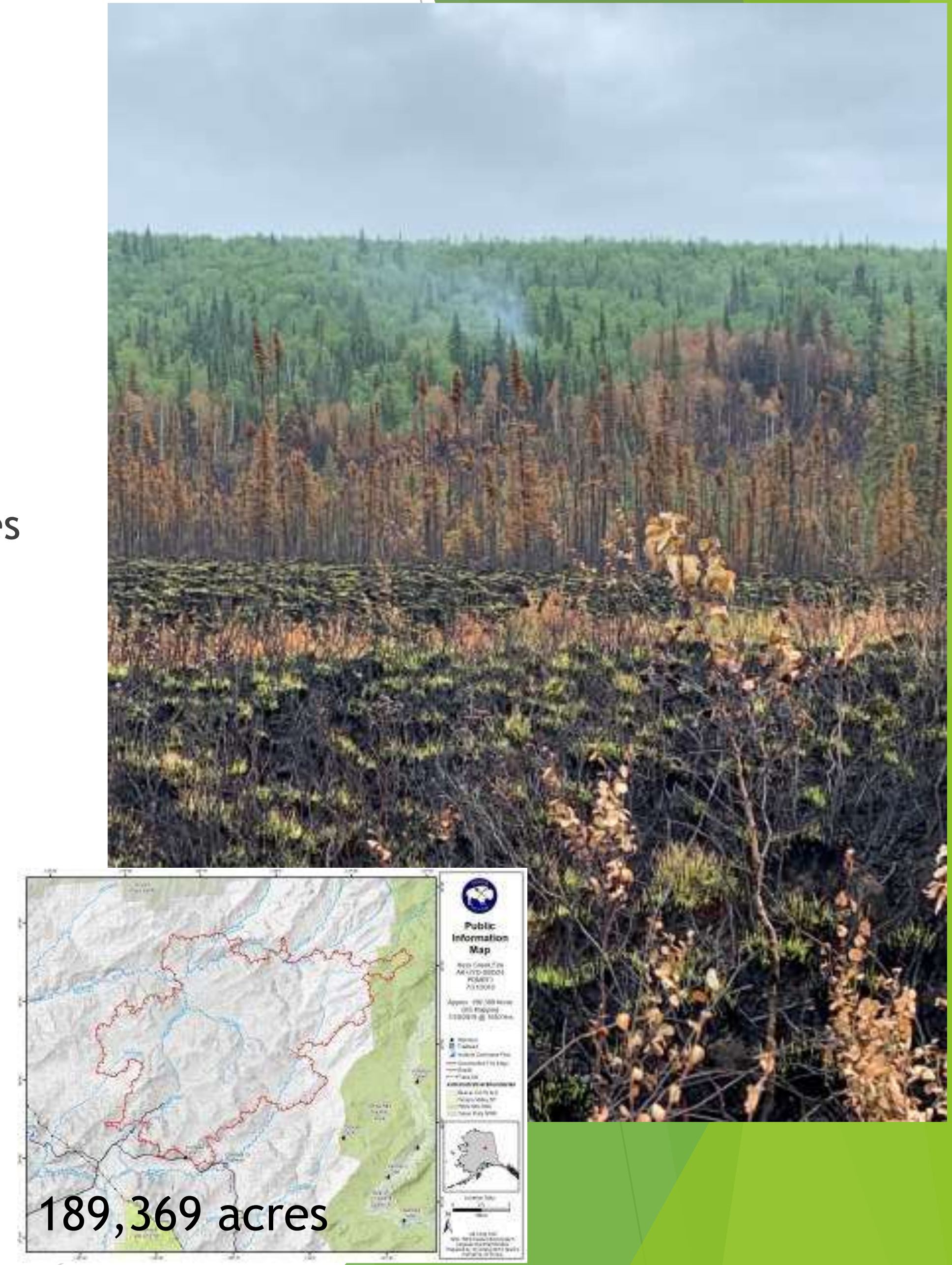
# Boreal forests of Interior Alaska

- In Alaska, 30-40% of the area is considered boreal forest, with black spruce being the most common boreal forest type

- Typical forest types:
  - Black spruce forests on north-facing slopes (often underlain by permafrost)
  - Black spruce bogs (often underlain by permafrost)
  - White spruce, birch, and aspen on warmer, south-facing slopes

# Alaska and Fire

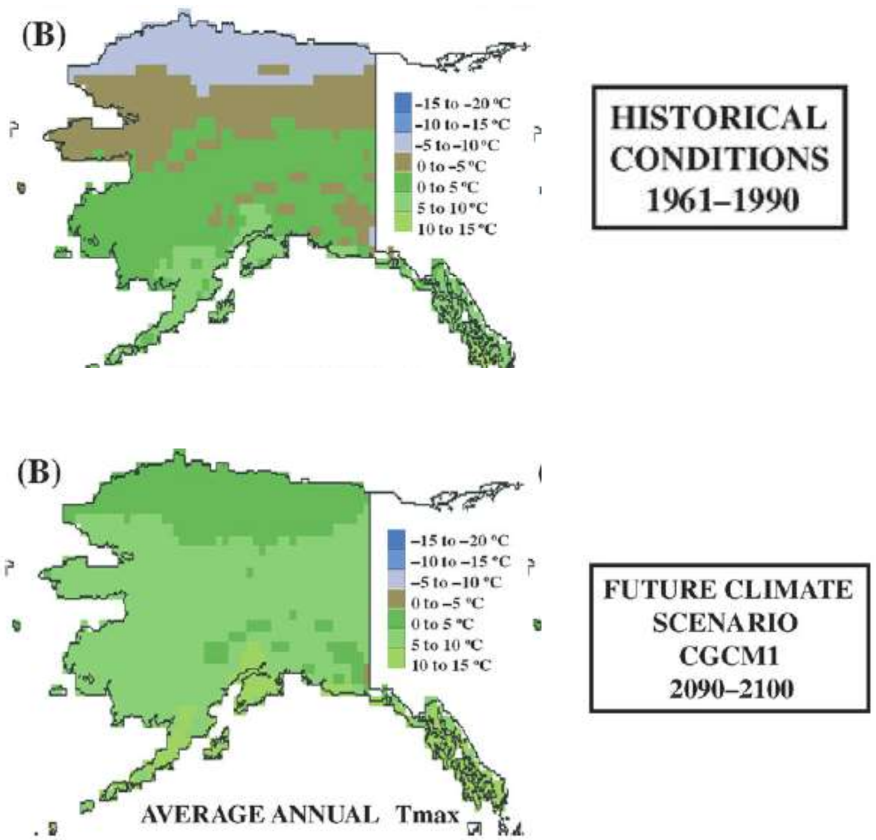
- Fire plays a key role in maintaining black spruce on the landscape
  - Black spruce is well adapted to regenerate following fire
  - Has several competitive advantages over other (deciduous) species
    - serotiny
    - shallow roots
    - germinates on organic soils
- Historically wildfires took place every 50-150 years
- Fire-free periods allowed adequate time for those species which were dominant prior to fire to reestablish and grow to reproductive maturity
  - ~30 years for black spruce

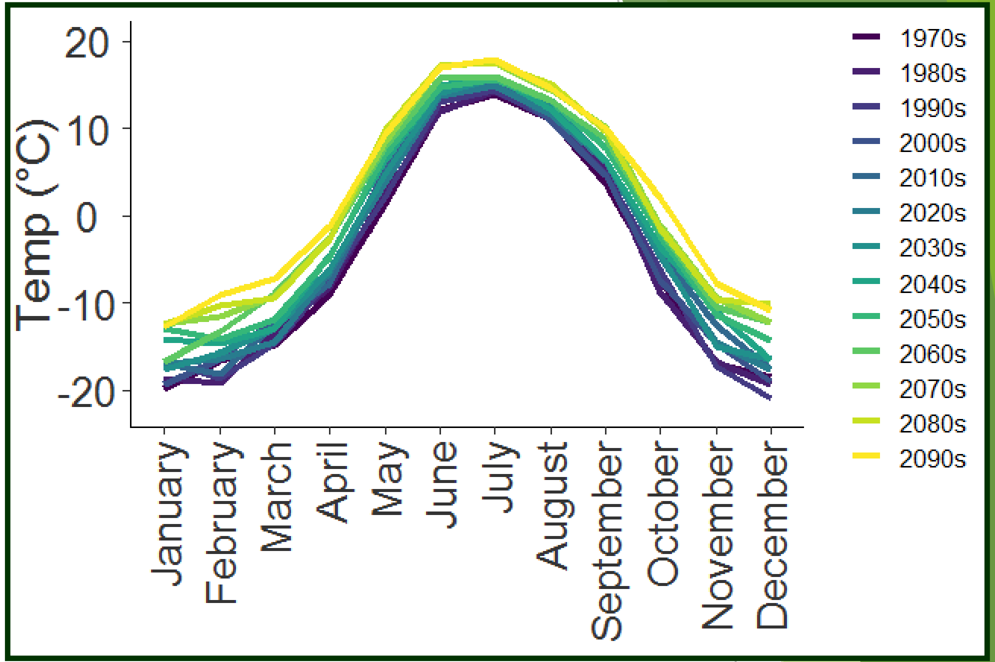


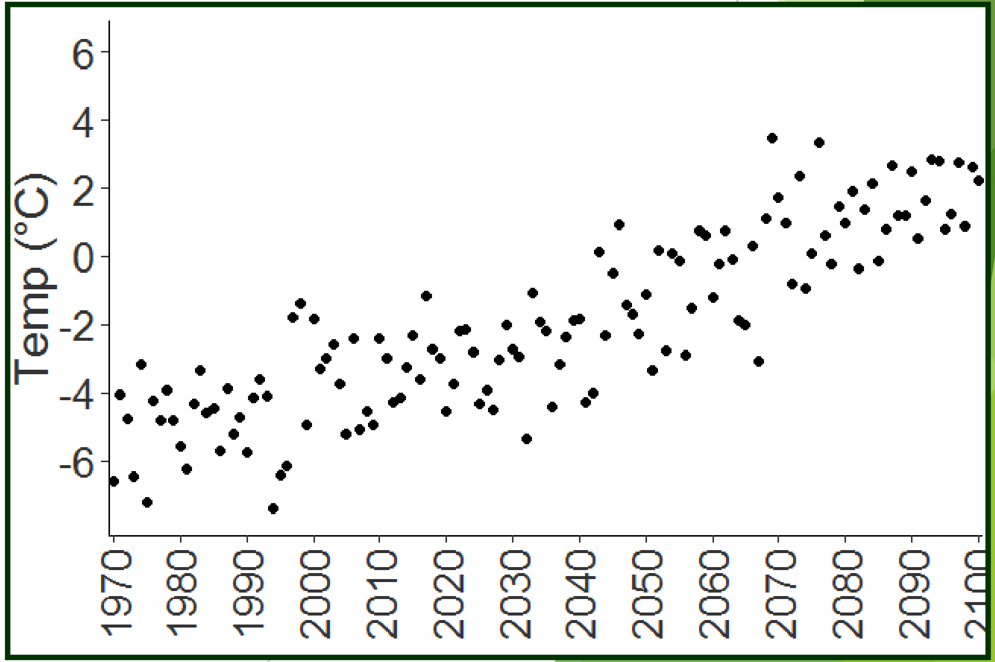
# Climate change in AK

**Simulating the response of natural ecosystems and their fire regimes to climatic variability in Alaska[1]**

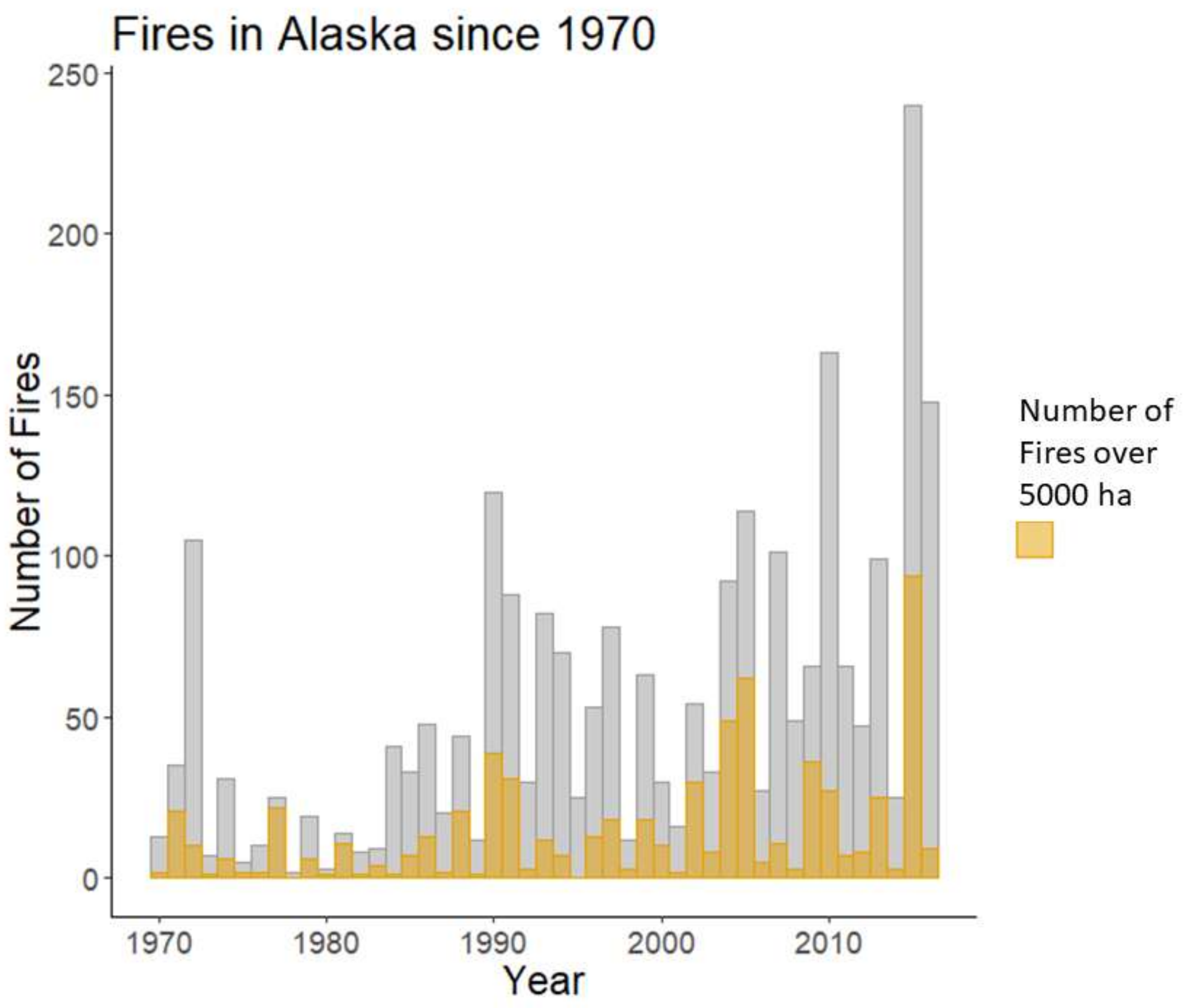
D. Bachelet, J. Lenihan, R. Neilson, R. Drapek, and T. Kittel

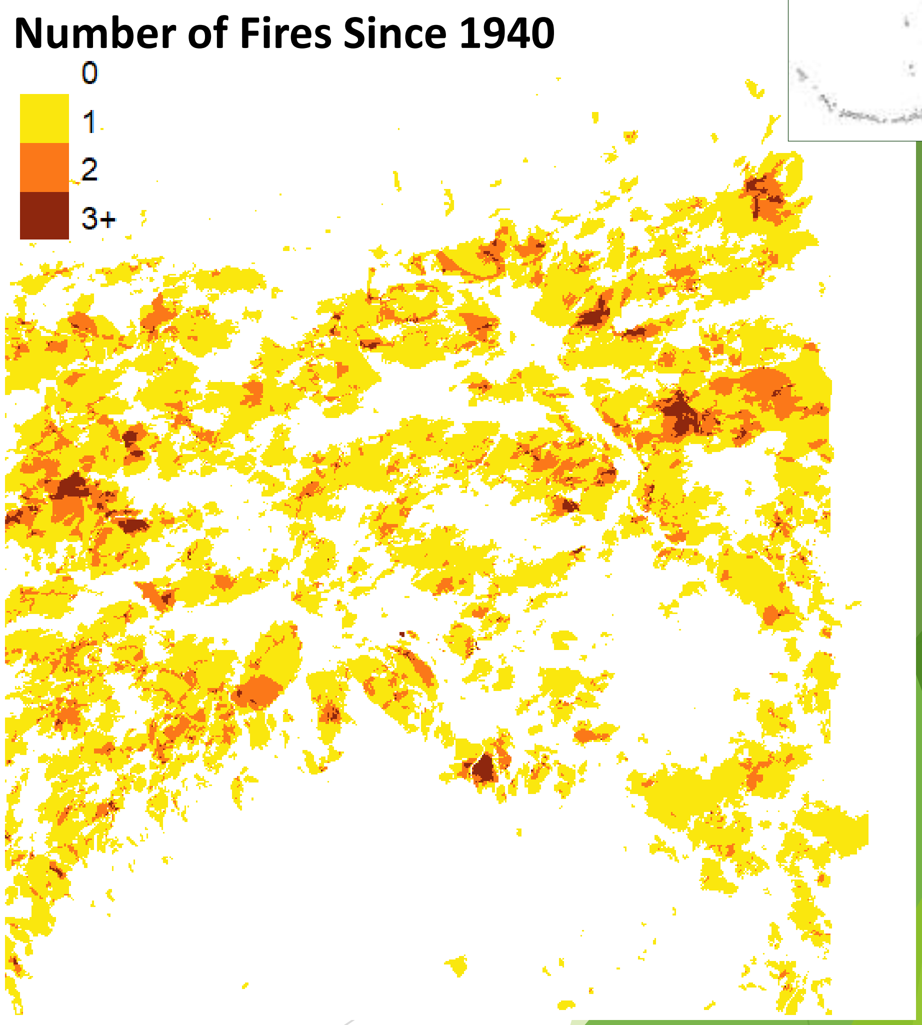


# Alaska Fire Trends




# Fire, CC and Permafrost

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D1, 8148, doi:10.1029/2001JD000438, 2003

**Impacts of wildfire on the permafrost in the boreal forests of Interior Alaska**

Kenji Yoshikawa,[1] William R. Bolton,[1] Vladimir E. Romanovsky,[2] Masami Fukuda,[3] and Larry D. Hinzman[1]



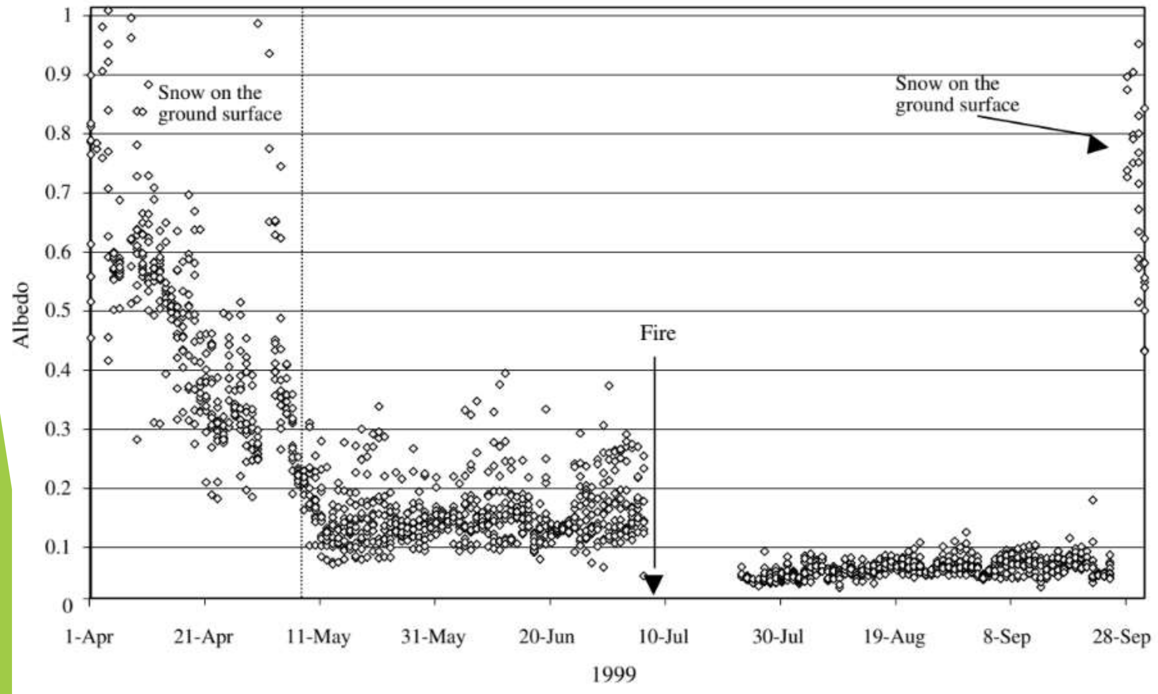



**Figure 5.** There are strong differences in albedo before and after wildfire. During snowmelt, the albedo ranges from 0.2 to 0.9 or more, decreasing to about 0.14 on a feathermoss surface prior to the fire. The albedo drops to 0.07 at a moderately burned site after the fire. Plotted data are the daytime (0600–1700 AST) averages.



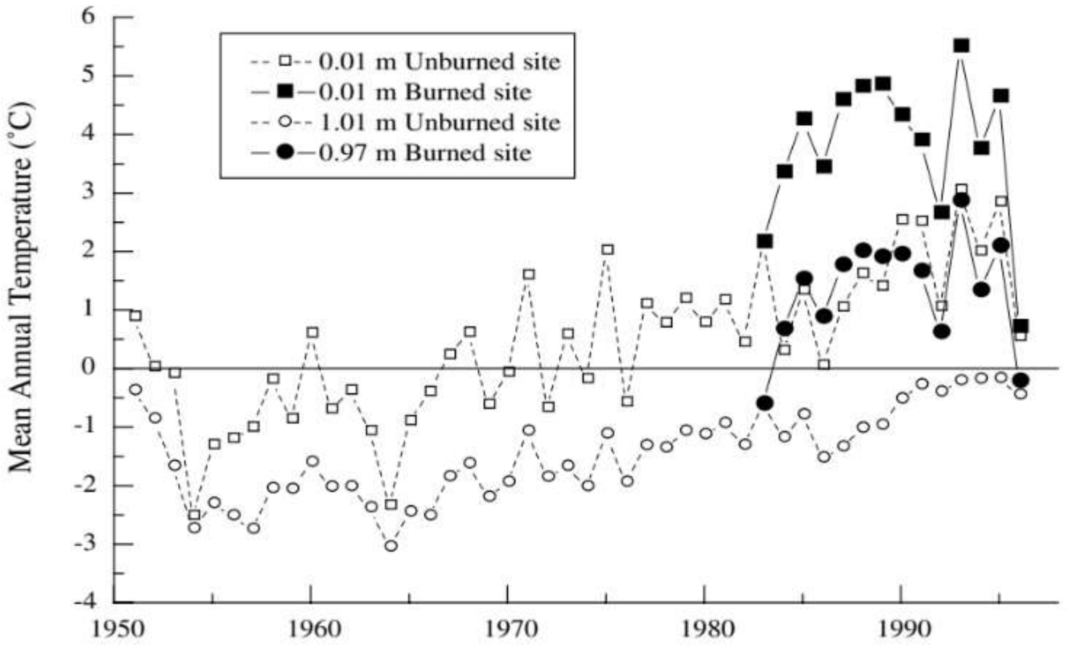
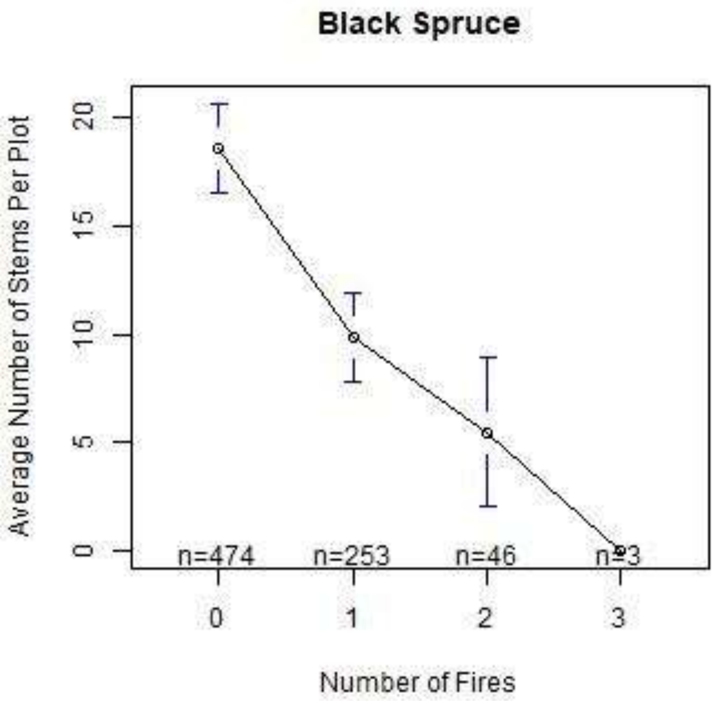



**Figure 9.** Modeled mean annual temperature at the ground surface (open and filled squares) and at 1 m depth (open and filled circles) at an unburned site (open symbols) and at burned site 5 (filled symbols).

# How does increasing fire frequency alter successional trajectories of aboveground vegetation in interior Alaska?

# What are the mechanisms?

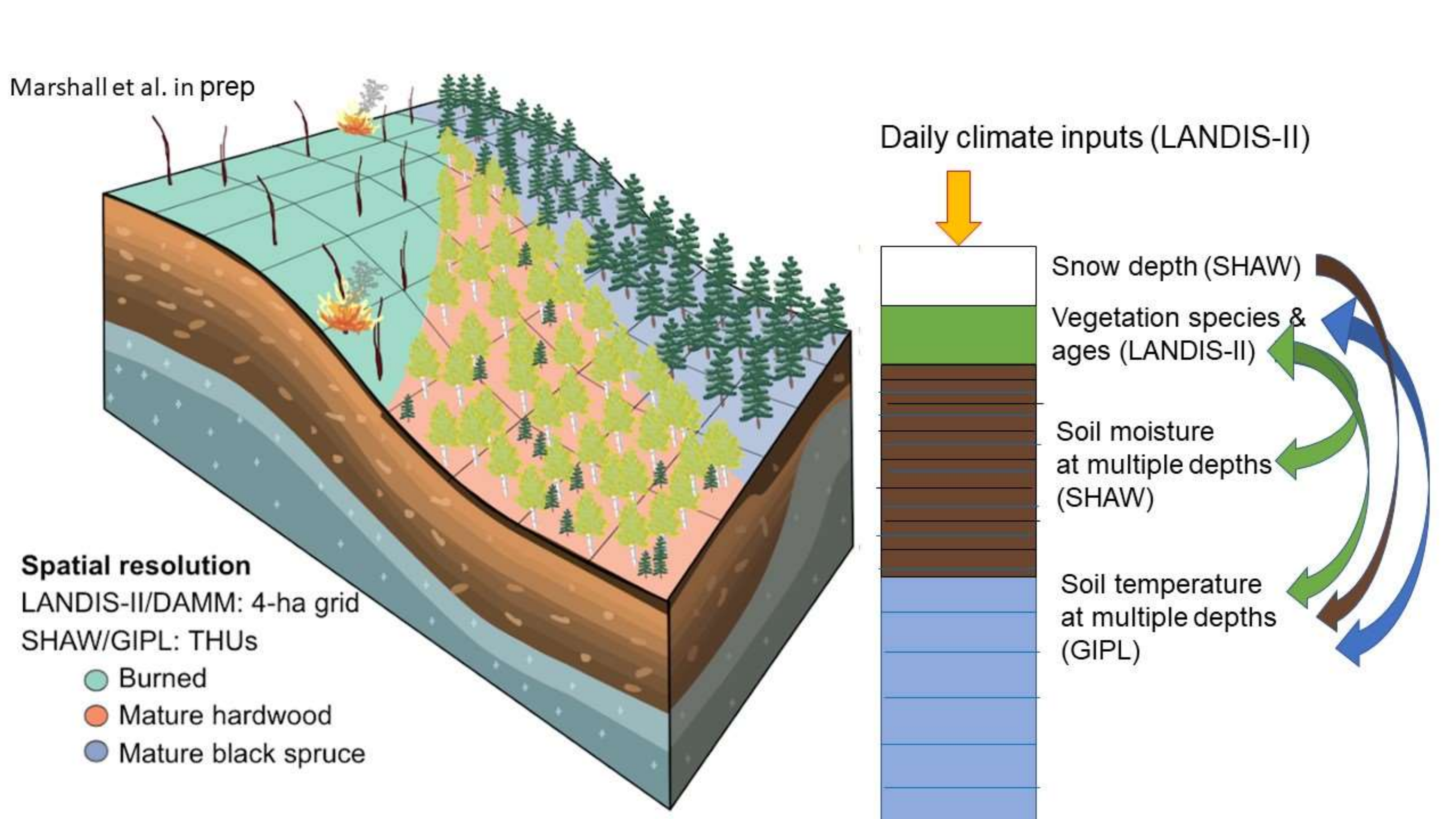
*… and how can we model them?*




- Fire returns before black spruce is sexually mature
- Organic layer thickness declines with more fire, removing spruce competitive advantage to establish
- Permafrost thawing allows for greater rooting depths, removing spruce's competitive advantage to persist long-term

# A new extension for Alaska

*DGS: DAMM-McNiP, GIPL and SHAW*

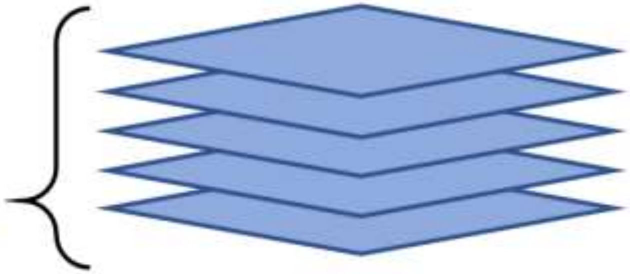


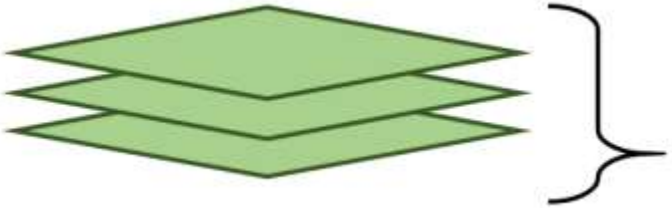
# MODEL INPUT DATA AND SOURCES

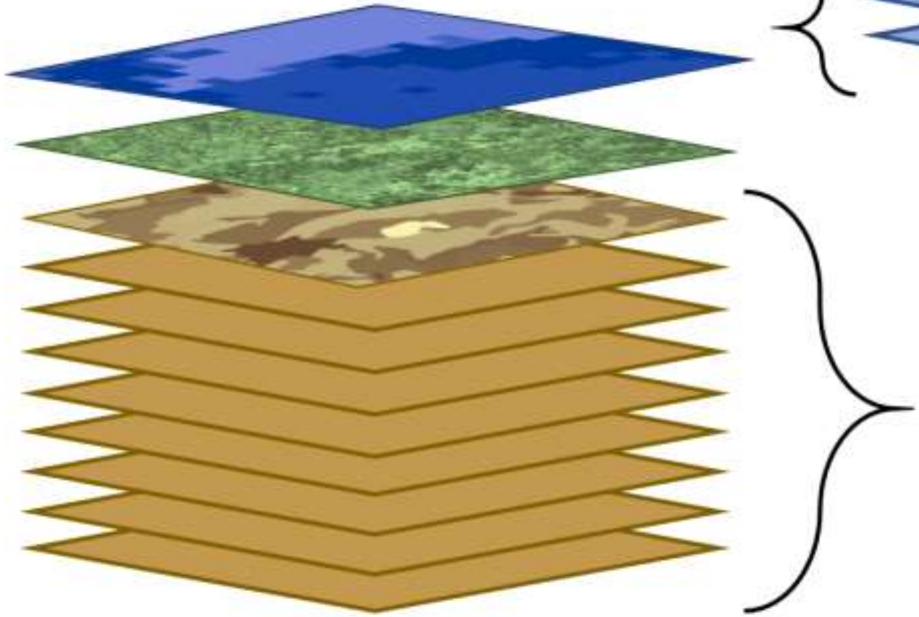
**Climate regions map & modeled climate data using:**

SNAP historic and projected dynamically downscaled climate data at 20 km resolution

- Temperature
- Precipitation
- Wind speed and direction
- Relative Humidity
- Shortwave Radiation







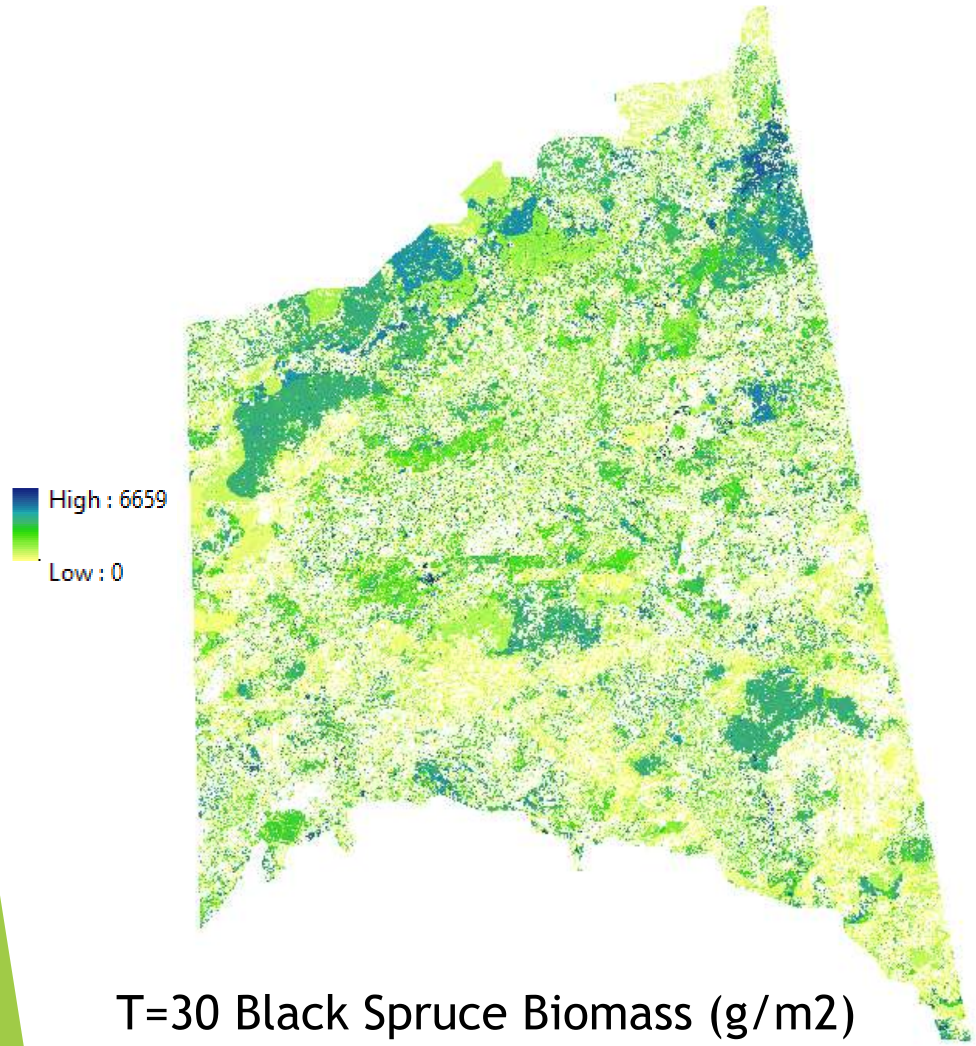
**Species composition map, created using:**

- Forest Inventory Analysis dataset for Interior AK
- Alaska Center for Conservation Science vegetation wetland composite map
- Digital Elevation Map

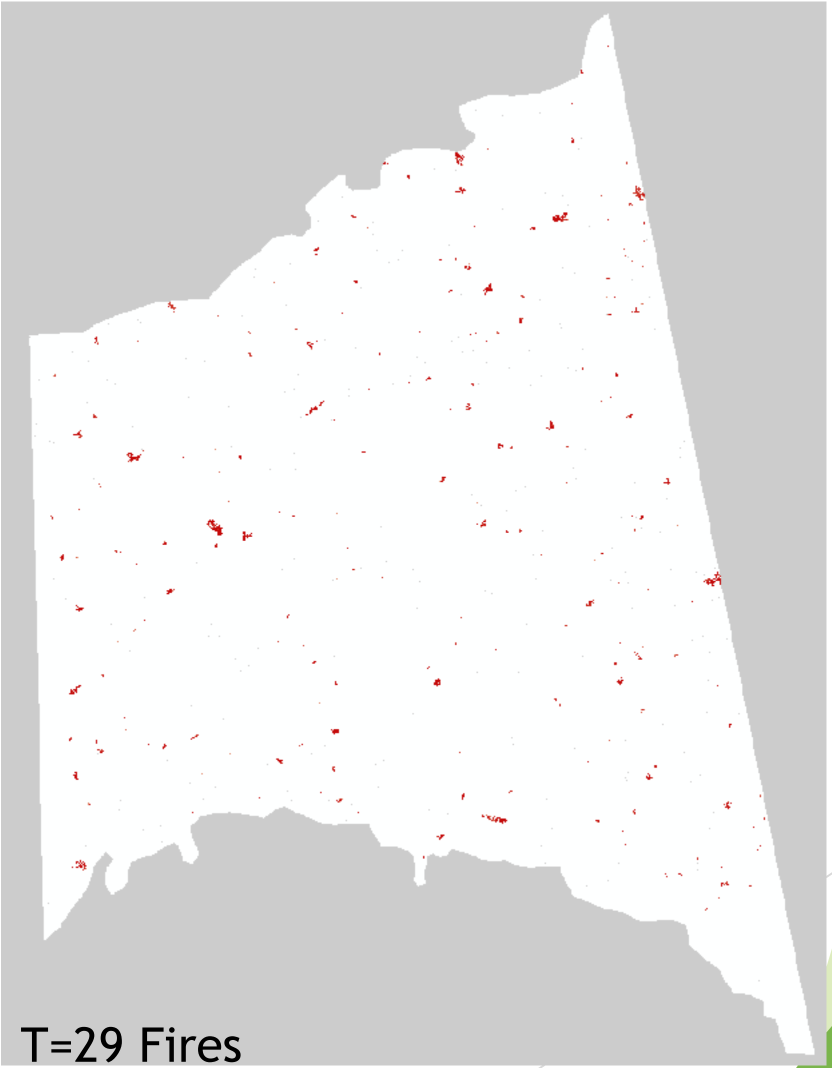
**Soil maps from STATSGO, including:**

- Depth
- Texture
- Carbon
- Nitrogen
- Drainage

# Output

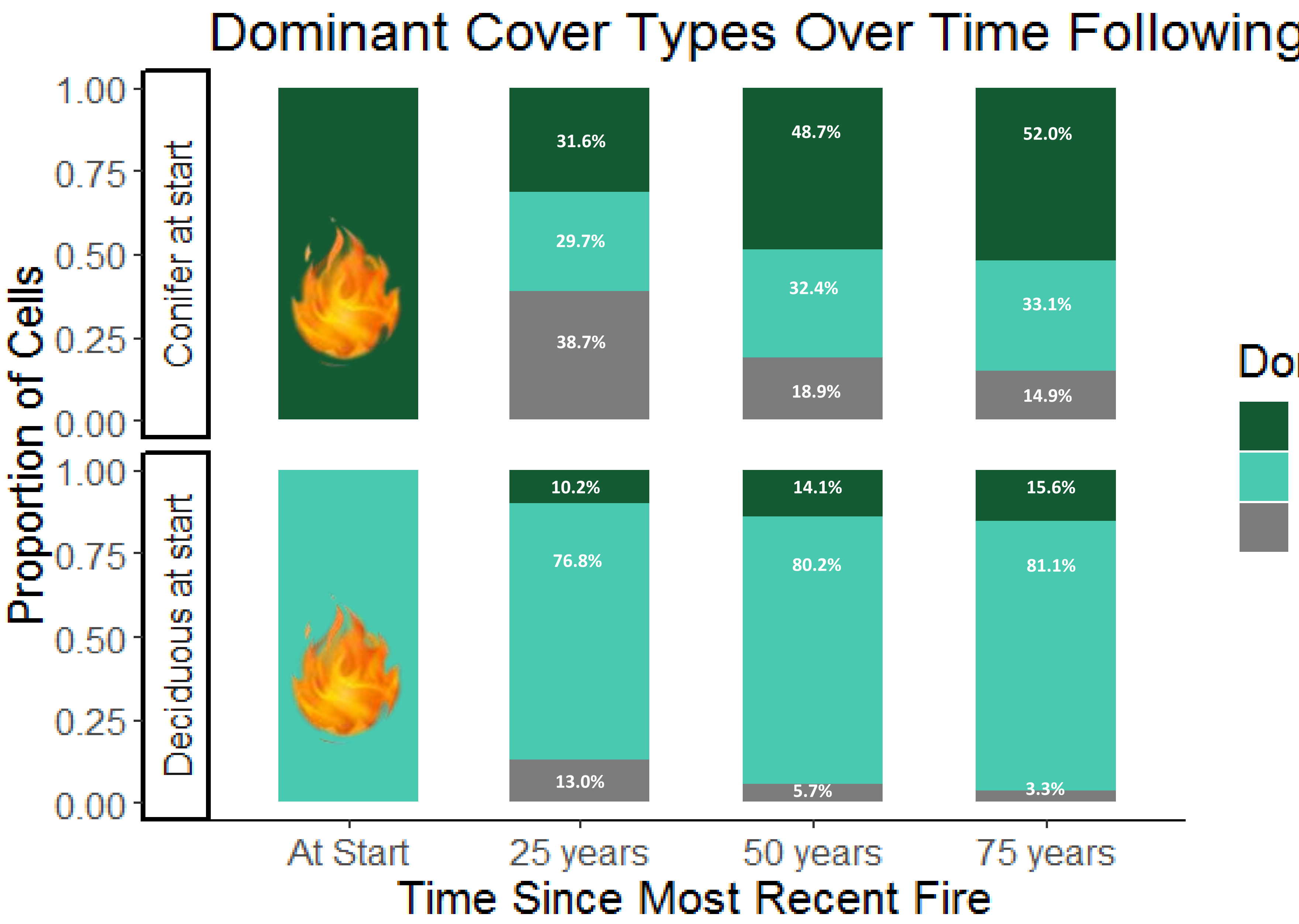



T=30 Black Spruce Biomass (g/m2)

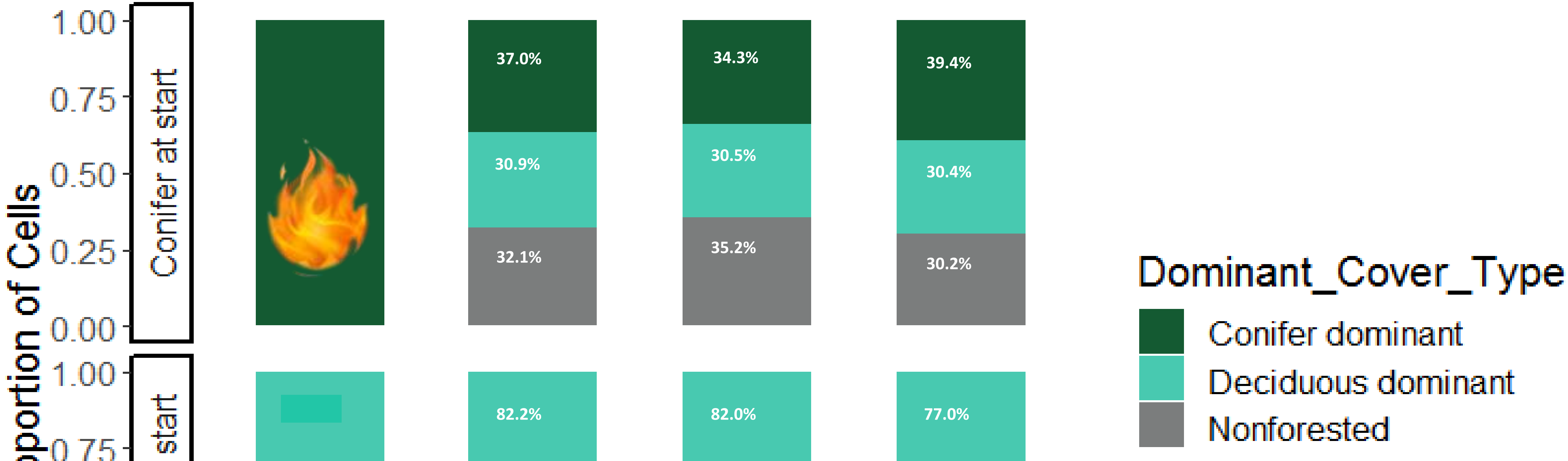


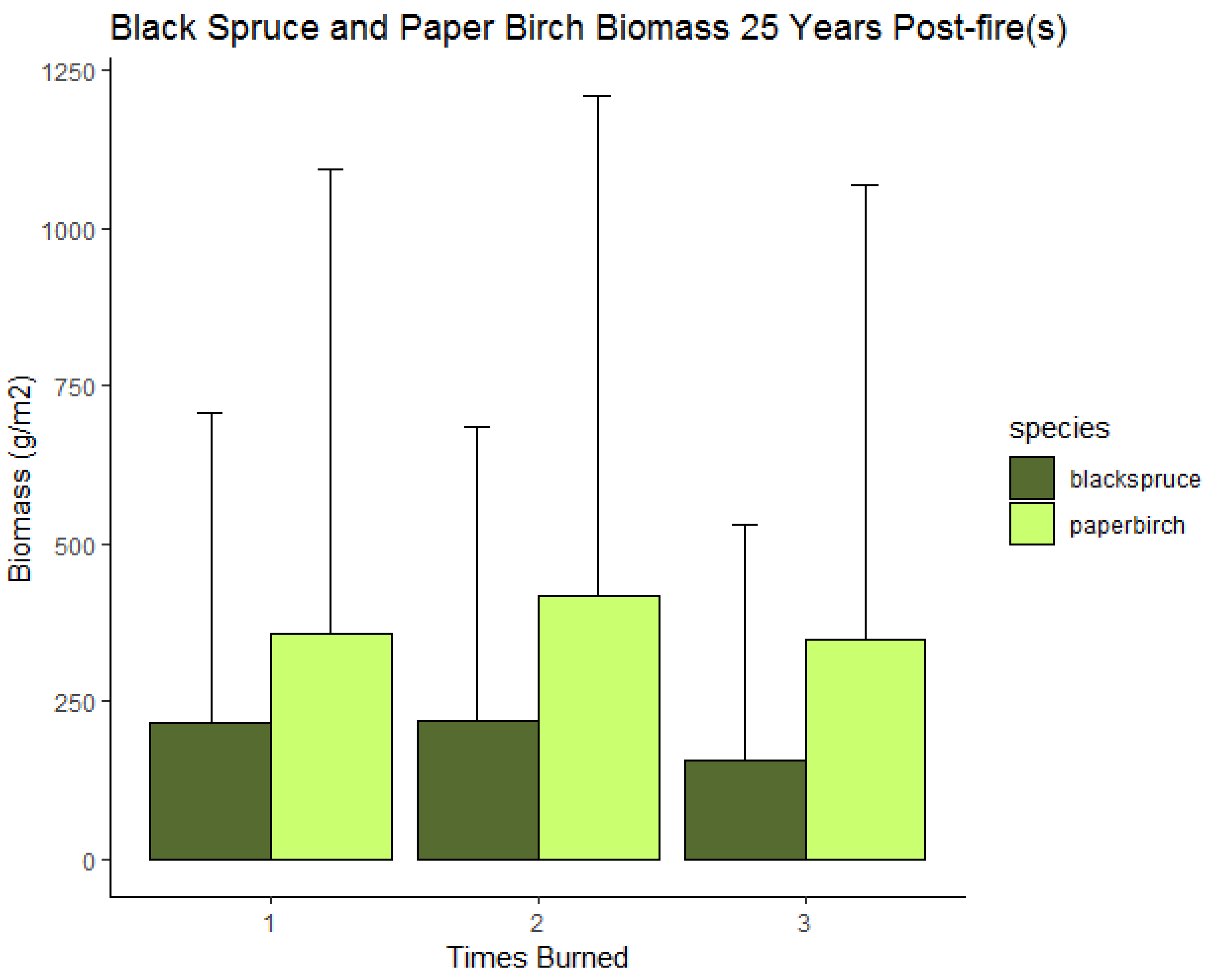
T=29 Fires

Will depend on the extensions you're using

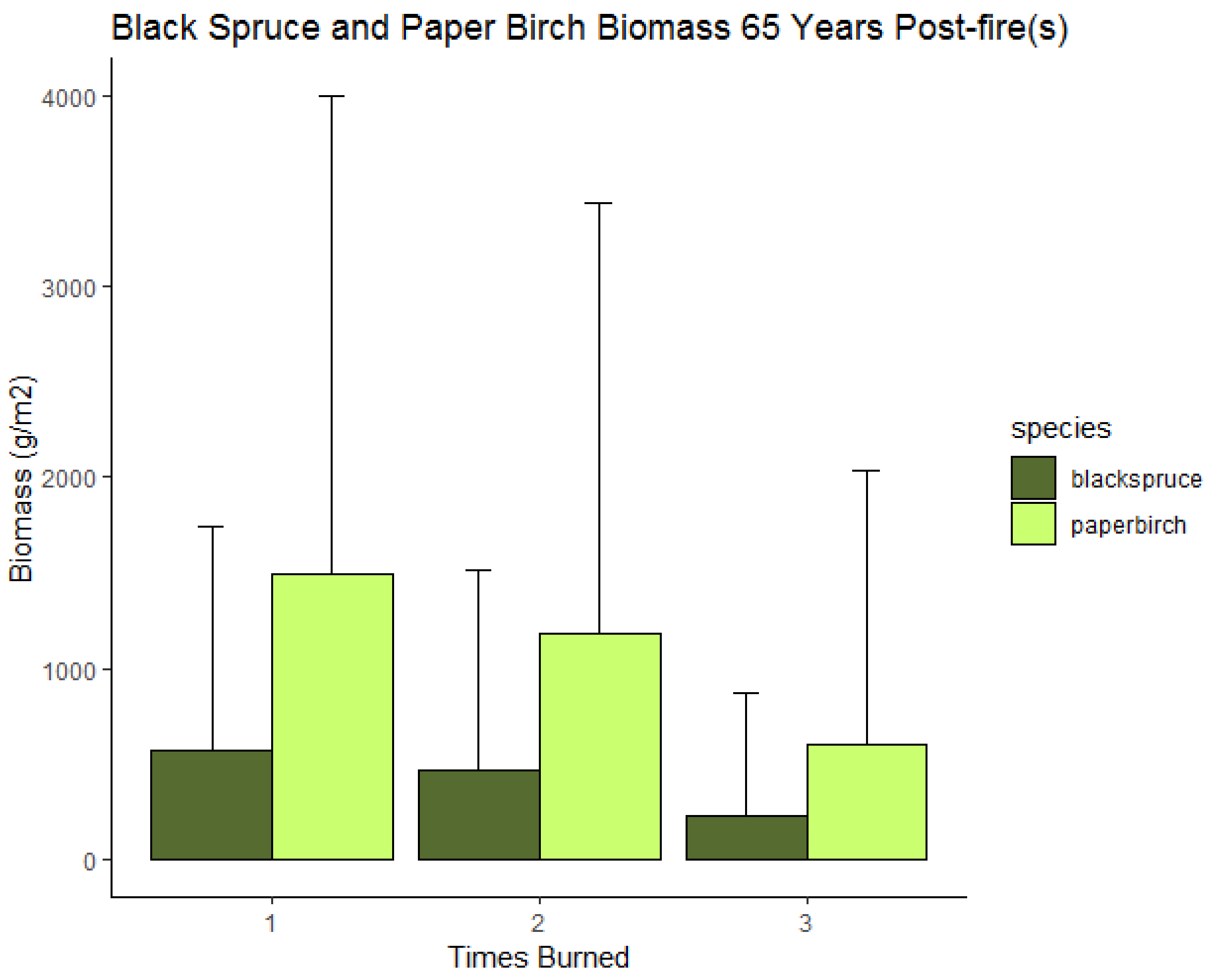

Dominant Cover Types Over Time Following One Fire
Proportion of Cells
1.00
0.75
0.50
0.25
0.00
Conifer at start
Deciduous at start
31.6%
29.7%
38.7%
48.7%
32.4%
18.9%
52.0%
33.1%
14.9%
10.2%
76.8%
13.0%
14.1%
80.2%
5.7%
15.6%
81.1%
3.3%
At Start
25 years
50 years
75 years
Time Since Most Recent Fire
Dominant_Cover_Type
Conifer dominant
Deciduous dominant
Nonforested

# Dominant Cover Types Over Time Following Three Fires



Black Spruce and Paper Birch Biomass 25 Years Post-fire(s)
Biomass (g/m2)
1250
1000
750
500
250
0
1
2
3
Times Burned
species
blackspruce
paperbirch

Black Spruce and Paper Birch Biomass 65 Years Post-fire(s)
Biomass (g/m2)
4000
3000
2000
1000
0
1
2
3
Times Burned
species
blackspruce
paperbirch

# This work is ongoing! We are working on…

- A more complete representation of species composition
- Using the fully coupled DGS extension to LANDIS-II
- Comparing trends under historic climate versus RCP 8.5 CC scenario
- Modeling dynamic fire with SCRPPLE- make fire responsive to CC
- Investigating spatial patterns and changes in carbon source/sink status

# My Takeaways about Simulation Modeling (with LANDIS-II)

- Know your question
  - Are you using the right tool?
  - Can/should the tool be adjusted?
- Know your system (or the people who do…)
  - Modeling is done best when it's collaborative
- Get comfortable working with messy data
- Understand the limitations
- Understand what is 'emergent' vs. 'prescribed'

# Thank you!

UAF
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University of Idaho

NC STATE UNIVERSITY

Portland State

UF
UNIVERSITY of FLORIDA

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LANDIS-II